GEOCHEMISTRY OF VOLCANIC ROCKS, ROUND MOUNTAIN MINING DISTRICT, NEVADA

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INTRODUCTION

The timing of mineralization and the geochemical relations of the mineralization to the composition of the host volcanic rocks are important aspects of exploration for volcanic rock hosted Au-Ag deposits. Volcanic rock-hosted epithermal ore deposits have contributed significant quantities of gold to the total recorded gold production in the Great Basin, and the Round Mountain, Nevada, open-pit gold deposit presently contributes over 100,000 oz/year to Nevada's ample production. This paper reviews the geochemistry of the volcanic rocks in the Round Mountain mining district and the timing of hydrothermal activity in relationship to the chemical evolution of the volcanic rocks.

GEOLOGIC SETTING

REGIONAL GEOLOGY

The Round Mountain mining district is located in central Nevada, adjacent to the Great Smoky Valley on the western flank of the Toquima Range (fig. 1). East and south of Round Mountain are lower Paleozoic sedimentary rocks which have been intruded by Cretaceous granitic rocks (Kleinhampl and Ziony, 1985). The Paleozoic rocks consist of Cambrian to Ordovician schist, phyllite, argillite, quartzite, and limestone that are complexly folded and faulted. Cretaceous granite intrudes the older rocks and makes up the core of the Toquima Range southeast of the gold-bearing lodes. This intrusion has been dated at 90–100 m.y. (Shawe, 1977). Both the granite and the Paleozoic rocks were intruded by andesite and rhyolite dikes approximately 35 m.y. ago (Marvin and others, 1973). East of Round Mountain the dikes and older rocks are intruded by an Oligocene granodiorite stock. Oligocene to early Miocene ash-flow tuffs overlap the older rocks and serve as host rocks for the Round Mountain lode gold deposits.

The lode gold deposits occur within a major caldera complex possibly consisting of five or more individual calderas. We informally refer to the collective collapses as the Mount Jefferson Complex and the individual calderas as the Moores Creek, Round Mountain, Mount Jefferson, Trail Canyon, and Monitor calderas. At the present time, the association of the Monitor caldera and Mount Jefferson complex is inferred from preliminary geologic mapping (R. Hardyman, personal commun., 1986). Boden (1986) mapped the regional volcanic stratigraphy of the Round Mountain area, but he did not recognize the Round Mountain caldera as an independent eruptive event.

GEOLOGY OF THE LODE GOLD DEPOSITS

Tingley and Berger (1985) considered the lode deposits at Round Mountain to be within the ring fracture zone of a largely buried caldera structure. Evidence for the presence of this caldera includes a welded rhyolite ash-flow tuff megabreccia unit underlying the host tuffs originally mapped by Shawe (1981) and all of these volcanic units overlap pre-Tertiary bedrock east and south of Round Mountain. In addition, the host tuffs are considerably thicker than normal for extra-caldera outflow, with the single cooling unit exceeding 1,400 ft in thickness, consisting of an approximately 500-ft thick lower non-welded ash-flow base, an intermediate 800-ft thick welded segment and an upper 100-ft thick non-welded top.

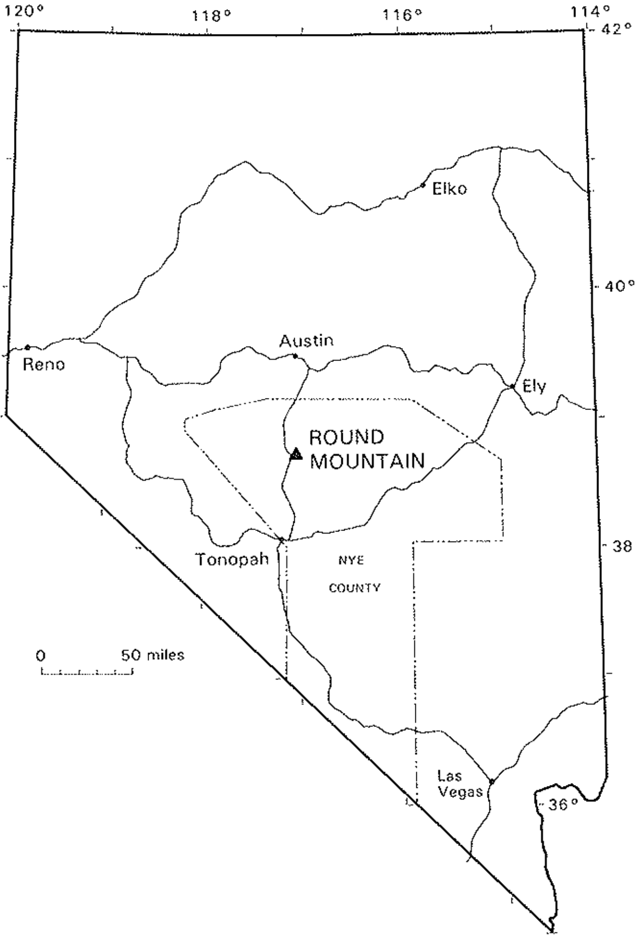

FIGURE 1. Location map, Round Mountain, Nye County, Nevada.

Boden (1986) recognized several major eruptive units in the general vicinity of Round Mountain. He mapped the megabreccia unit east of Round Mountain (cf. Shawe, 1981) as the "megabreccia of Dry Canyon" and obtained a biotite age of 32.3 ± 0.7 m.y. from a vitrophyric zone in the welded matrix. As was suggested by Shawe (1977) and Berger and Tingley (1980), Boden attributed the megabreccia to collapse in a caldera now largely buried by the fill in the Great Smoky Valley. Overlying the megabreccia unit is the main host of gold mineralization in the Round Mountain district, the tuff of Round Mountain. The tuff of Round Mountain is known from drill data to lie directly on the megabreccia in the mining area (Tingley and Berger, 1985).

Boden (1986) correlated the tuff of Round Mountain with the lowermost tuff of Mount Jefferson exposed northeast of Round Mountain, on the basis of trends in modal mineralogy, chemical composition, minor mineralogy, and K-Ar ages. Tingley and Berger (1985), in part based on the data of Harrington (1985), considered the tuff of Round Mountain to be a separate cooling unit from any of the tuffs filling the Mount Jefferson caldera. Tingley and Berger (1985) found the stratigraphy at the Gold Hill Mine north of Round Mountain to be similar to that at Round Mountain and to be overlapped by Mount Jefferson outflow. Tingley and Berger (1986) found the tuff of Round Mountain to have no cooling breaks and to contain up to 30% broken euhedral crystals of quartz, sanidine, plagioclase, and biotite (in order of relative abundance) in a groundmass of devitrified glass. In comparison, Harrington (1985) found the lowermost tuff of Mount Jefferson to consist of two distinct members separated by a cooling break. Both of these lowermost members contain about 20% phenocrysts; plagioclase is the most abundant silicate phase present and is more abundant in the younger member. Harrington (1985) found the tuff of Mount Jefferson to become progressively more mafic upward in the pile, and described a two-pyroxene flow in the uppermost sequence of tuffs filling the Mount Jefferson caldera.

Tingley and Berger (1985) described a thin veneer of epiclastic rocks, consisting of tuffaceous sandstone, conglomerate, and thinly laminated siltstone, on the top of Round Mountain. Thinly laminated beds of chalcedony and chalcedony plus pyrite within the sedimentary rocks are interpreted by Tingley and Berger (1985) to be chemical sediments related to the geothermal activity associated with the gold mineralization.

MINERALIZATION

The exploration history in the Round Mountain mining district probably dates back to the 1860's or 1870's, but it was not until 1906 that rich showings of free gold were discovered and the attention of the mining world was drawn to Round Mountain. Between 1906 and 1969, the lode mines (including Gold Hill) produced 346,376 oz of gold and 362,355 oz of silver from 936,962 tons of ore. Since 1979, the Smoky Valley Mining Company has produced gold and silver from 12,000,000 tons of ore averaging 0.062 oz gold and 0.07 oz silver per ton. In 1982, the estimated reserves were increased to more than 200 million tons containing over 8 million oz of gold and over 15 million oz of silver.

There are four general types of gold-silver ore at Round Mountain—vertical veins and sheeted zones, low-angle fractures, breccias, and tabular disseminated ores (Tingley and Berger, 1985). All of the ore types are structurally and genetically interrelated, and their variations in form reflect physical properties of the host rocks. The mineralogy of the ores is relatively simple, consisting of free gold, electrum, realgar, fluorite, stibnite, quartz, adularia, and illite. Because of widespread oxidation, the completeness of this mineralogical listing in uncertain.

Berger and Tingley (1980) attributed the gold and silver mineralization at Round Mountain to very shallow epithermal conditions. The Round Mountain gold deposit is a hot-spring type epithermal occurrence (Berger and Eimon, 1983; Berger, 1985; Berger and Silberman, 1986) based upon the following evidence: (1) the presence of a central breccia pipe on Round Mountain containing reverse stratigraphy (i.e., blocks of stratigraphically higher units in the pipe as much as 100–150 ft below the original stratigraphic position); (2) the presence of chemically derived bedded chalcedony in the epiclastic rocks; (3) the occurrence of chalcedony-pyrite beds in the epiclastic rocks showing evidence of consanguinous sedimentation and hydrofracturing (M. Sander, Stanford University, personal commun., 1984); and (4) the occurrence of laterally injected breccia veins during explosive eruption and boiling of the hydrothermal fluids.

HOST-ROCK GEOCHEMISTRY

UNALTERED ROCKS

The major and trace-element chemistries of the basement and volcanic rocks in the Round Mountain mining district are given in table 1. The tuff of Round Mountain is a high-silica, high-potassium rhyolite (Ewart, 1979) and the tuff of Mount Jefferson varies from a high-potassium rhyolite near its base to a high-potassium dacite at the top of Mount Jefferson (Harrington, 1985). The data of Shawe and Lepry (1985) indicate the megabreccia of Dry Canyon is a low-silica, high-potassium rhyolite.

Based upon a detailed petrographic and geochemical study of the tuffs within the caldera complex, Harrington (1985) found the tuff of Mount Jefferson to be the most strongly zoned tuff in the area. SiO_2 in this tuff ranges from 76.2 to 67.2% (wt) and the most siliceous rocks are at the base of this pile. K_2O follows silica in abundance with a range of 6.45 to 3.89% (wt) and is most enriched in the lowermost tuffs. Total iron, MgO, CaO, and Na_2O increase in concentration upward in the volcanic pile. Strontium content ranges from 415 ppm to 538 ppm and rubidium content ranges from 115 ppm to 138 ppm. Harrington (1985) mapped high silica-potassium rhyolite dikes intruding the lower part of the tuff of Mount Jefferson.

Because of limited geographic exposure and extensive hydrothermal activity, the tuff of Round Mountain is more difficult to characterize chemically than the tuff of Mount Jefferson. At the sampled locality, it contains about 76% SiO_2, 204 ppm Sr, and 158 ppm Rb. Boden (1986) reported a range in SiO_2 content of about 74–77% (wt).

The megabreccia of Dry Canyon was analyzed by Shawe and Lepry (1985). They found 69.2% (wt) SiO_2 in two chilled rings around a breccia block, with accompanying 4.2% (wt) and 5.2% (wt) K_2O.

HYDROTHERMALLY ALTERED ROCKS

The tuff of Round Mountain and megabreccia of Dry Canyon are altered in the vicinity of Round Mountain. The megabreccia of Dry Canyon contains illite and montmorillonite where sampled adjacent to the Round Mountain townsite. The megabreccia shows little change in SiO_2 and K_2O content, but there is a significant increase in Al_2O_3 from about 14 to 18% (wt). CaO and Na_2O are strongly depleted in the altered rock decreasing by an order of magnitude. About 3 ppb Au and 32 ppm As were detected.

The tuff of Round Mountain was sampled by Shawe and Lepry (1985) on the top of Round Mountain *per se*. In spite of the presence of secondary quartz, adularia, and illite (as reported by Tingley and Berger, 1985), the total silica content reported by Shawe and Lepry (1985) is less than in the unaltered rock. There is little change in Al_2O_3, but K_2O is significantly increased and CaO and Na_2O are strongly depleted. Arsenic and antimony are enriched. Uranium and particularly Th appear to be slightly depleted. Data presented by Tingley and Berger (1985) show the host rocks at Round Mountain to be enriched in gold, arsenic, and antimony.

TABLE 1. Major and trace-element chemistry of Tertiary volcanic rocks in the Round Mountain mining district and vicinity, Nevada.

Major element data by A. Hubert, and by Shawe and Lepry (1985); trace-element data by INAA.
n.d. = no determination made; -- = no INAA available for sample.

	Sample No.										
	1	2	3	4	5	6	7	8	9	10	11
Major elements (weight-percent)											
SiO_2	76.18	75.3	69.5	68.4	70.54	73.81	73.41	69.9	72.4	71.4	86.5
Al_2O_3	14.31	12.4	15.9	15.4	18.66	13.70	16.80	16.4	12.9	13.6	10.07
Fe_2O_3	1.49	1.46	2.77	2.70	2.29	1.49	1.01	0.36	1.5	0.62	0.13
FeO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.24	0.32	0.20	n.d.
MgO	0.10	0.41	1.15	0.76	0.25	0.24	0.16	0.13	0.05	0.00	0.01
CaO	1.27	0.77	3.17	2.24	0.50	1.23	0.57	0.31	0.37	0.41	0.22
Na_2O	2.84	2.33	3.37	3.58	0.66	3.01	1.69	2.5	1.6	0.29	1.39
K_2O	4.79	4.67	3.74	4.42	3.98	4.70	8.75	6.1	7.4	10.9	2.07
TiO_2	0.20	0.16	0.44	0.39	0.41	0.22	0.28	0.41	0.41	0.30	0.23
P_2O_5	n.d.	<0.05	0.16	0.13	n.d.	n.d.	n.d.	0.08	0.10	0.10	n.d.
MnO	n.d.	<0.02	0.05	0.04	n.d.	n.d.	n.d.	0.03	0.03	0.03	n.d.
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.07	0.03	0.12	n.d.
H_2O+	n.d.	2.31	1.04	n.d.	n.d.	n.d.	n.d.	1.7	1.4	0.54	n.d.
H_2O-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.64	0.30	0.17	n.d.
Trace elements (parts per million)											
As	7.0	3.9	7.1	8.3	31.5	27.2	104.	40.	130.	69.	67.4
Sb	1.87	1.42	0.87	1.04	3.45	218.	70.04	4.7	56.	17.	2350.
Au	0.00	0.00	0.00	0.00	0.0026	0.0168	0.0159	--	--	--	0.0264
U	5.35	6.4	0.0	0.0	5.22	3.47	2.9	5.45	4.19	434.	0.0
Th	18.7	23.0	12.9	15.4	18.0	11.0	13.0	14.4	7.70	14.5	0.82
Cs	4.54	4.55	4.3	4.41	8.84	16.2	17.5	--	--	--	12.5
Rb	158.	200.	116.	136.	138.	179.	502.	--	--	--	42.5
Sr	204.	78.7	538.	415.	99.7	<70.	138.	--	--	--	<70.
Ba	780.	421.	1340.	1290.	991.	120.	922.	--	--	--	358.
Eu	0.656	0.446	1.09	1.0	0.92	0.294	0.555	--	--	--	0.857

1. Unaltered welded tuff of Round Mountain, Shale Pit hill
2. Unaltered, lowermost welded tuff of Mt. Jefferson
3. Unaltered, uppermost welded tuff of Mt. Jefferson
4. Unaltered, uppermost welded tuff of Mt. Jefferson
5. Altered, megabreccia of Dry Canyon
6. Altered non-welded tuff, Gold Hill Mine
7. Altered welded tuff, Gold Hill Mine
8. Altered welded tuff of Round Mountain (analysis #20, Shawe and Lepry, 1985)
9. Altered, upper non-welded tuff of Round Mountain (analysis #21, Shawe and Lepry, 1985)
10. Altered, upper non-welded tuff of Round Mountain (analysis #22, Shawe and Lepry, 1985)
11. Chalcedonic sinter, Gold Hill Mine

As mentioned previously, we interpret the stratigraphy at the Gold Hill Mine to be essentially the same as that at Round Mountain and the alteration is of the same style. The major element trends are the same as at Round Mountain. Assuming that the stratigraphic equivalency is correct, then, of the trace-elements, cesium, arsenic, and antimony are strongly enriched, rubidium may be enriched slightly to strongly, strontium is strongly depleted, uranium and thorium are depleted, and barium may be depleted. The altered samples at Gold Hill contain about 16 ppb Au.

DISCUSSION

REGIONAL RELATIONSHIPS

Silberman and others (1976) recognized three major volcanic rock associations in the Great Basin related to the tectonic evolution of the region. They related the middle Cenozoic calc-alkaline intermediate to silicic volcanism to subduction along the boundary between the Pacific and North American plates. The silicic ash-flow tuffs of the Mount Jefferson area are part of a middle Oligocene to middle Miocene sequence of rhyolite to quartz latite eruptions (43–17 m.y.) that superceded the earlier, predominantly andesitic to quartz latitic magmas. The more silicic magmas are believed to be derived from the differentiation of basaltic and andesitic parent compositions (Silberman and others, 1976; Hildreth, 1981). The lower volumes of more intermediate composition flows probably stem from changes in the tectonism in the region prior to the onset of basin-and-range faulting between about 20 and 17 m.y. ago (McKee, 1971).

The volcanic rocks that erupted between 43 and 17 m.y. ago in the Great Basin appear to form an east-west trending belt from southwestern Utah through central Nevada into eastern California (Silberman and others, 1976). Presumably this trend is controlled by a zone of deep-seated east-west structures that provided the primary access for magma ascent. Based upon mappable faults and geophysical lineaments, Ekren and others (1976) postulated several such structures in a region that includes Round Mountain. This structural control was superceded in central Nevada after about 20 m.y. by the northwest-trending Walker Lane.

Albers and Kleinhampl (1970) noted the association of epithermal ore deposits in the Great Basin to volcanic centers. Silberman and others (1976) stressed that all of the largest precious-metal deposits in western Nevada are in andesitic to dacitic volcanic rocks (e.g., Comstock Lode, Tonopah, and Aurora), while some important, but smaller, districts are found in complex rhyolitic volcanic centers (e.g., Round Mountain, Bullfrog, and Wonder). Of all the historic gold production in Nevada from volcanic rock hosts, about 11% has come from volcanic centers 43 to 17 m.y. old, and 30% of this proportion is from rhyolitic host rocks (Silberman and others, 1976).

LOCAL RELATIONSHIPS

The whole-rock geochemistry of the unaltered rocks helps in the classification and correlation of the host volcanic rocks in the Round Mountain mining district and vicinity. The data support the hypothesis of Tingley and Berger (1985) that the tuff of Round Mountain was derived from a separate magma and caldera than the tuff of Mount Jefferson. In addition to containing more Rb, Th, and U than the tuff of Mount Jefferson, the tuff of Round Mountain also contains appreciably less strontium and barium and a much more pronounced chondrite-normalized negative europium anomaly. Although the K-Ar age determinations do not uniquely define the stratigraphic relationships, our data are consistent with the observable geologic relationships that the tuff of Round Mountain is older than the tuff of Mount Jefferson.

The mineralization ages at Round Mountain (Tingley and Berger, 1985) suggest that the geothermal activity was consanguinous with the latest intrusive and eruptive events in the Mount Jefferson caldera or followed very shortly thereafter. This timing may put the mineralization at about the same time as the emplacement of rhyolite domes into the ring fracture zone of the Mount Jefferson caldera as noted by Harrington (1985), although no precise ages are available for the domes. The whole-rock geochemistry of the domes indicates that they were not derived from the same immediate magma as the two-pyroxene, high-potassium dacite flow that caps Mount Jefferson and is the youngest eruptive event within the Mount Jefferson caldera.

The relationship of the primary volcanic rock chemistry to the geochemistry of the mineralization at Round Mountain is equivocal because no data are available on the composition of the heat source. However, the field relationships indicate that the heat source was rhyolitic rather than dacitic. Tilling and others (1973) showed that the gold abundance in unaltered plutonic and volcanic rocks does not vary by much more than an order of magnitude; therefore, the composition of the original source rock may be of less importance than the concentrating processes that took place within the hydrothermal fluid. Fluid-inclusion studies at Round Mountain (L. Rowen, U.S.G.S., unpub. data, 1984) show the fluid salinities to have been quite low. It seems likely that the fluids did not circulate through a sedimentary rock basement where higher salinities could have been acquired, but rather through one of primarily granitic composition. This interpretation is consistent with the low base-metal concentrations found in the Round Mountain ores by Tingley and Berger (1985), and the report that base-metal concentrations do not appear to increase with depth (Berger and others, 1981).

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